FREQUENCY DEPENDENCE OF THE PARAMETERS OF AN INDUCTION DISCHARGE IN ARGON AT ATMOSPHERIC PRESSURE

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The discharge parameters have been examined as functions of field frequency via numerical solutions for a steady induction discharge at atmospheric pressure without gas flow.

Various approximations are involved in theoretical estimation [1] of the optimal frequency range; in particular, no allowance was made for the plasma radiation, and the results were [1] of qualitative type. The optimum frequency [1] was calculated as $35/d^2$ MHz, this being the frequency giving a specified maximum temperature with minimal power input W and Iw (number of ampere-turns per unit length of coil). Here, d is the tube diameter in cm. If the skin layer thickness is small relative to the tube radius ρ_0, a simple relation was given [1] between Iw and the maximal plasma temperature T_{max}, which does not contain the frequency f or ρ_0, namely

$$\int_0^{T_{max}} \varkappa(T)\,\sigma(T)\,dT = \left(\frac{Iw}{2}\right)^2 \tag{1}$$

Here $\varkappa(t)$ and $\sigma(t)$ are the thermal and electrical conductivities of the plasma.

Figures 1-3 and the table below give numerical results for argon at atmospheric pressure in a tube with internal radius $\rho_0 = 1.5$ cm. Curves 1-6 represent respectively f of 100, 26, 10, 5, 1, and 0.5 MHz, while curves shown with primed numbers in Fig. 1 correspond to the axial temperature. Parts a-c of Fig. 2 correspond to f of 100, 10, and 0.5 MHz, while the following table corresponds to the axial temperature t(0) = 8500°K:

f	0.5	1.0	5.0	10	26	(MHz)
Iw	135	68	18	16	100	(A-turns/cm)
W	0.18	0.18	0.19	0.27	13	(kW/cm)
W_*	20	20	21	23	47	%
β	1.2	2.5	12	25	65	—

Here W_* is the radiative loss per unit length of discharge as a percentage of the total power supplied.

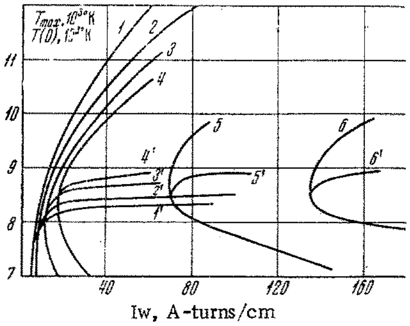

Fig. 1

The calculation involves [2] computer solution of the equations for the electromagnetic field and energy conservation together with the yield of transmitted radiation. A discharge in argon at atmospheric pressure has the temperature distribution deep within the discharge largely unaffected by radiation transport in strongly reabsorbed parts of the spectrum unless the difference between the maximum and axial temperatures exceeds 2000-3000°K.

A substantial increase in Iw is needed at low frequencies in order to maintain a sufficiently strong field. The region of maximum current density shifts outward as the frequency increases on account

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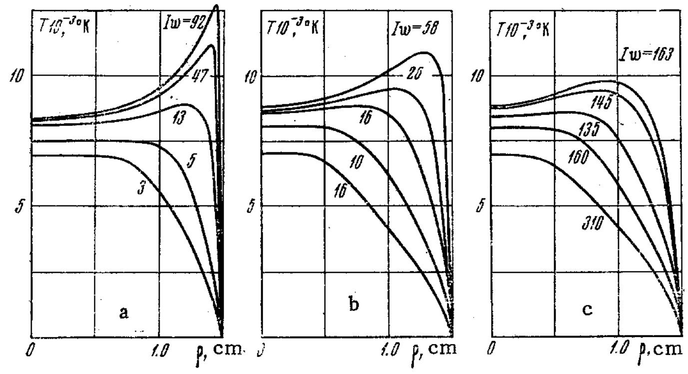

Fig. 2

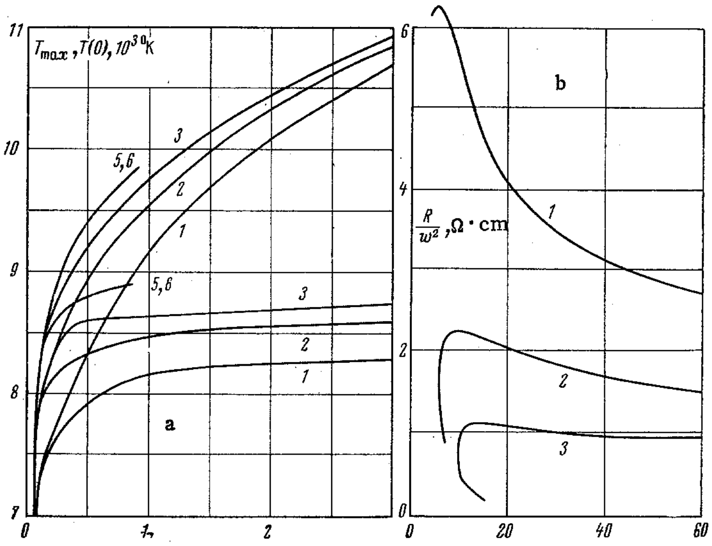

Fig. 3

of the fall in the thickness of the skin layer. The increased temperature gradient increases the heat flux to the wall, and so the power input has to be increased. If T(0) = 8500°K (a relatively low figure), the table shows that the best frequency range is 5-10 MHz, which is close to the recommended [1] range $10 \leqslant \beta \leqslant 20$, where

$$\beta \equiv \frac{2\rho_0^2}{\delta^2} \gg 1, \quad \delta = \frac{c}{2\pi \sqrt{\sigma(T_{\max}) f}}$$

with ρ_0 and δ in cm, f in Hz, and σ (T) in cgs electrostatic units.

The importance of radiation increases rapidly with Iw and W, which results in a difference between T(0) and T_{max}; also, both temperatures become dependent on f for a given Iw, including when $\beta \gg 1$.

For instance, $\beta = 200$ for $f = 100$ MHz [T(0) = 8330°K] when Iw = 60 A-turns/cm, while $\beta = 13$ for $f = 5$ MHz [T(0) = 8900°K] and the T_{max} (12,000 and 10,600°K) differ by more than 1000°K (Fig. 1), but the difference between T(0) and T_{max} is the larger, which means that (1) is clearly inapplicable.

Figure 1 shows that $(Iw)_{min}$ is rather dependent on f.

Figure 2 gives radial temperature distributions for various f and Iw. The distribution is governed largely by T_{max} over a wide frequency range, and the temperature corresponding to $(Iw)_{min}$ is only slightly dependent on frequency.

Figure 3a shows that T_{max} is governed almost entirely by W at all f, i.e., by

$$W = \frac{R}{w^2}(Iw)^2$$

not simply by $(Iw)^2$, as (1) would imply. Here R is the specific resistance of the discharge.

Figure 3b shows R/W^2 as a function of Iw at various f, which peaks at a certain Iw and thereafter falls as Iw increases the more rapidly the higher f. Also, R increases with f.

These relationships may be of value in estimates and in choosing working conditions for induction discharges.

LITERATURE CITED

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